

IN THE SPECIFICATION:

Please amend the follow paragraphs of the originally filed specification as follows:

[8] It is another object of the present invention to improve the performance of radiation sensors using an attenuator with a high level of attenuation, which protects the UV detector from degradation after exposure of the radiation sensor to high doses of UV radiation.

[10] It is also an object of the present invention to improve radiation sensor tolerance and extend a time period between calibration using information about temperature and total ~~accumulative~~ accumulated dose during the sensor operation.

[13] The radiation sensor, according to the present invention, includes one or more simple and efficient filters made of plastic plates for correction of the spectral sensitivity of different photodiodes used therein.

[24] FIG 6 shows [[a one]] an embodiment of a UV sensor for sensing radiation density (irradiance) from different light guides according to the present invention.

[34] A radiation sensor according to the present invention is an optical electronic device for measuring UV irradiance from high intensity UV sources. One of the embodiments of the radiation sensor optimized for using in UV curing chambers comprises a housing, a housing lid, an attenuator, a detector, a preamplifier, an amplifier, a controller with an analog to digital converter, one or several push buttons, memory, a display, batteries and a power supply. The front view of the radiation sensor is shown in Fig. 1. A housing 1 has a display 2 and a Power button 3 and a Mode button 4. The back view of the radiation sensor is shown in Fig. 2A. The housing 1 has dimensions of 100 mm x 100 mm x 12 mm and is closed with a lid 56. There is a thermo isolative material under the lid that protects any electronics inside from excessive heat during operation. The lid 56 is secured with screws 57 and has a window 5. The view of the radiation sensor without lid is shown in Fig. 2B. The housing 1 holds a printed circuit board 34A and batteries 18. The printed circuit board 34A has an opening in the center with an adjustable insert 32. The opposite side of the adjustable insert 32 is fixed inside of an attenuator 6. The attenuator 6 is shown with a thin line as it is located under the

printed circuit board 34A and secured with screws 30A through holes in the printed circuit board 34A. A photodiode 34 is inserted in the attenuator 6 through another opening on the printed circuit board 34A. The printed circuit board 34A has a reserved place for soldering a surface mount photodiode 34B. ~~For some embodiments as~~ As the [[one]] embodiment shown in Fig. 2C, the printed circuit board 34A has [[with]] only the photodiode 34B installed thereon. To work with the photodiode 34B the same attenuator 6 is rotated around the insert 32 and secured with screws 30A in a second position as shown in Fig. 2C. For some embodiments, both photodiodes 34, 34B are installed and the attenuator is modified to have one first cavity and two secondary cavities associated with both photodiode 34, 34B. The photodiode 34 or the surface mounted photodiode 34B can be a silicon carbide UV A, UV B, or UV C photodiode, a GaAsP UV photodiode, an AlGaIn UV photodiode, and a GaN UV photodiode.

[37] The design of a multi-cavity attenuator, according to the present invention, is shown in Fig. 4. The lid 120 has an entrance aperture 121 (diameter of 3 mm) with a window 122. The printed circuit board 126A has a hole under the window 122 to let light enter inside of the first cavity 124 (a cylindrical hole with a 5 mm diameter and a 7.5 mm depth) of an attenuator body 123 made of fluoropolymer or metal (such as aluminum or stainless steel) to scatter and redirect the light inside the first cavity 124. The window 122 comprises a sapphire plate which has extremely high resistance to scratching. For some embodiments the window 122 is made as a positive lens to correct a spatial response of a radiation sensor. The attenuator body 123 is attached to the printed circuit board 126A with screws 123A and has a second cavity 125 (a cylindrical hole with a 8.5 diameter and a 7.5 mm depth), which directs scattered and attenuated light to a photodiode 126. The internal surface of the first and second cavities comprises a machined surface of ~~fluoropolymer~~ fluoropolymer or metal without any reflective or absorptive coatings. In case of a metal attenuator body, the machined surface is preferably polished to provide multiple reflection with low attenuation after each reflection. The radiation entered into the first cavity 124 is reflected, scattered and redirected therein, and only portion of it (less than 1 %) enters into the second cavity 125. There is a hole 123C (diameter of 2 mm) in the wall 123B (of 2 mm thick) between the first cavity 124 and the second cavity 125. The radiation entered into the second cavity 125 is reflected, scattered and redirected therein such that it is again attenuated in more than 200 times. The size of the hole 123C is chosen to obtain an appropriate total attenuation of attenuator because the amount of radiation that pass from the first cavity into the second

cavity is approximately proportional to the surface area of the hole 123C. Such a multi-cavity design provides of attenuator with a high level of attenuation and a small size so as to reduce the size of a radiation sensor comprising the attenuator.

[40] An adjustable attenuator with a detector is shown in Fig. 5A. The lid 127 has an entrance aperture 128 (diameter of 3 mm) with a window 129. The printed circuit board 134A has a hole under the window 129 to let light enter inside of the first cavity 131 of an attenuator body 130. The attenuator body 130 is attached to the printed circuit board 134A with screws 130A and has a second cavity 133, which directs scattered and attenuated light to the photodiode 134. An optical filter 135A is placed in front the photodiode 134. There is a hole 130C in the wall 130B between the first cavity 131 and the second cavity 133. The first cavity 131 (a cylindrical hole with a 5 mm diameter and a 7.5 mm depth) has an adjustable insert 132 made as a brass tube polished inside and having an outside diameter 5 mm, an inner diameter 4 mm, and a 7.5 mm length. The adjustable insert 132 can be moved to change the open area of the hole 130C to obtain an appropriate total attenuation of attenuator. Fig. 9A shows a perspective view of the adjustable insert 132. The adjustable insert 132 has two notches 132A on its upper end to rotate the insert with a screwdriver for an adjustment. On its lower end, it has a cut segment 132B. By orientating the adjustable insert 132 differently relative to the hole 130C, different amount of radiation will pass from the first cavity 124 into the second cavity 125. In this embodiment, the interior surface of the insert 132 works as reflective surface of the first cavity 124. After adjustment, the insert 132 is secured with a screw 132A. The multi-cavity attenuator with such an adjustable insert operates in a much broader range of UV irradiance (e.g., from 100 W/cm² to 0.5 W/cm²) and measures more accurately. For example, radiation sensors with maximum range 10 W/cm² and 1 W/cm² need different attenuation to bring an output signal from the photodiode into the optimal range in which the photodiode works lineally and without saturation.

[41] The effects of a radiance incidence angle on a detector output is very important for many applications where light sources are different for calibration and for real measurements. An ideal irradiance detector has an angular response, which can be described as a cosine function of the angle of incidence. The proximity of the measured angular response to the theoretical cosine function shows the quality of a detector. The example of a theoretical cosine response in Polar and Cartesian Coordinates are shown in the International Light Measurement Handbook published by International Light, Inc. (Newburyport, MA)

(<http://www.intl-light.com/handbook/ch09.html>). A multi-cavity attenuator with an improved cosine response is shown in Fig. 5B. The lid 160 has a window 161. A fluoropolymer tape 162 (e.g., a white PTFE tape according to Mil.Spec.T-27730A, minimum of 99% Polytetrafluoroethylene, made by McMaster-Carr, Chicago, IL) is secured a sapphire plate 166 to [[near]] the window 161 with a washer 163. The sapphire plate 166 has a first portion with a diameter approximately equal to a diameter of a hole of the lid 161 and a second portion with a diameter smaller than the diameter of the hole of the lid 161. The printed circuit board 165 has a hole under the window 161 to let light enter inside of the first cavity 167 (a cylinder with a 5 mm diameter and a 7.5 mm deep) of an attenuator body 164 made of a fluoropolymer. The fluoropolymer has no absorption in visible and UV range and it is temperature resistant. It has white color and provides good diffuse reflection. The attenuator body 164 is attached to the printed circuit board 165 with screws 164A and has a second cavity 168 (a cylinder of a 8.5 mm diameter and a 7.5 mm deep) which directs scattered and attenuated light to the photodiode 173. The UV radiation from the first cavity 167 penetrates to the second cavity 168 through the semi transparent wall 164B of 0.2-5 mm thick between them. The first cavity 167 has an insert 171 made as a brass tube polished inside. The insert 171 has an outside diameter 5 mm, an inner diameter 4 mm, and a 5 mm length. The insert is secured with a screw 172. Fig. 9B shows a perspective view of the insert 171. The length L of the insert 171 and the thickness of the wall 164B between the cavities are chosen to obtain an appropriate total attenuation of attenuator. The attenuator body 164 is wrapped with a layer of another fluoropolymer tape 169 and then with a layer of aluminum foil 170. The fluoropolymer tape 169 and the aluminum foil 170 increase uniformity of a UV light field inside the first cavity and the second cavity to protect the fluoropolymer body from contamination and mechanical stress. The multi-cavity attenuator with a fluoropolymer tape directly under the window has a spatial response close to cosine as shown in Fig. 10.

[49] The detector can be adjusted and calibrated such that a certain irradiance signal should give a predetermined current. The detector is adjusted and calibrated by using regulate means to transfer maximum radiation, putting a light guide with a standard known irradiance (which is measured with an independent calibrated sensor), reading an output of the ~~radiation—detector~~ radiation detector, and using the regulate means to transfer radiation to have a predetermined output signal. Accordingly, the detector is calibrated and ready for

measurement. It has a specified sensitivity and an output current under the maximum irradiance which will not exceed allowed a current limit.

[52] In some embodiments, the radiation sensor has an optical filter 135A inside of the attenuator 130 (see Fig. 5A) to correct a spectral sensitivity of the photodiode 134. For example a cheap GaAsP UV photodiode Model No. G5842 made by Hamamatsu Photonics K.K. (Shizuoka Pref., 430-8587, Japan) ~~available at <http://www.hamamatsu.com/>~~ has a spectral response range from 260 nm to 400 nm and cannot be used as sensor for the UV A range without spectral correction with a long pass filter. A glass or interference optical filter can be used but they are expensive and usually have big dimensions. According to the present invention, a small polyester plate with thickness of 1m to 4 mm can be used together with the GaAsP G5842 photodiode to detect light of 320 nm to 400 nm that corresponds to the UV A range. Fig. 11 shows a spectral correction of a G5842 photodiode using a 1.6 mm polyester plate. A detector sensitivity for each specific wavelength is defined as a ratio of the detector output signal (e.g. output current for photodiodes) to irradiance level at the detector input, assuming that only narrow band radiation of this specific wavelength is present. Relative sensitivity for each wavelength is defined as a ratio of the detector sensitivity for this wavelength to the maximum detector sensitivity. The curve "a" shows the relative sensitivity of the G5842 photodiode without correction. The curve "b" shows the relative sensitivity of the photodiode with an additional 1.6 mm polyester plate for correction. The polyester plate absorbs radiation with a wavelength shorter than 320 nm forming consequently a sensitivity that corresponds to the UV A range (320-400 nm). Under the UV radiation, the polyester plate gradually changes transmission. The lifetime of the detector with the polyester long pass filter can be extended with a correction coefficient applied to the results of current measurements. The radiation sensor, after each run, renews data about the total cumulative dose measured after last calibration and the controller 10 applies a correction factor to compensate for variation in the detector sensitivity. Same correction methods are used if the detector changes its sensitivity after exposure to the UV radiation.

[54] Both embodiments in Figs. 11-12 described above use a cheap photodiode together with a small cheap plastic plate inside of the second cavity of the multi-cavity attenuator to form the spectral curve "b". This solution provide a cheap, compact and reliable alternative to an expensive silicon carbide photodiode (SiC) which has an internal interference optical filter for UV A and to a bulky silicon (Si) photodiode with a glass or

external interference optical filter. The outside temperature sensor ~~59A~~ 59A is optionally connected to the connector 59. The outside temperature sensor 59A may be a microchip digital temperature sensor, e.g., Model No. LM 74 made by National Semiconductor (Santa Clara, California) ~~available at <http://www.national.com/>~~. The temperature sensor 59A is located on the small printed circuit board and protected from direct UV light with an aluminum foil. The aluminum foil serves as substrate for materials used in UV curing procedure, such as paint, glue or compound. The radiation sensor with the outside temperature sensor 59A provides information of a real temperature profile that is very important for optimization of the technological procedure since the efficiency of the UV activation can be different for different temperatures and real temperature varies for different optical properties of the materials used. The outside temperature sensor 59A may be made as a disposable unit to be replaced with a new sensor after each run or can be made as printed circuit board with the sensor having a disposable aluminum cover.